Blade Motion Correlation for the Full-Scale UH-60A Airloads Rotor

Ethan Romander **Larry Meyn**
National Aeronautics and Space Administration
Ames Research Center
Moffett Field, CA

Danny Barrows
National Aeronautics and
Space Administration
Langley Research Center
Hampton, VA

Alpheus Burner
Jacobs Technology
Hampton, VA

Introduction

Testing was successfully completed in May 2010 on a full-scale UH-60A rotor system in the USAF's National Full-Scale Aerodynamics Complex (NFAC) 40- by 80-Foot Wind Tunnel.[1] The primary objective of this NASA/Army sponsored test program was to acquire a comprehensive set of validation-quality measurements on a full-scale pressure-instrumented rotor system at conditions that challenge the most sophisticated modeling and simulation tools. The test hardware included the same rotor blades used during the UH-60A Airloads flight test.[2] Key measurements included rotor performance, blade loads, blade pressures, blade displacements, and rotor wake measurements using large-field Particle Image Velocimetry (PIV) and Retro-reflective Background Oriented Schlieren (RBOS).

There have been many attempts to employ Navier-Stokes Computational Fluid Dynamics (CFD) and coupled CFD / comprehensive code techniques to correlate against similar datasets [3,4]. This latest dataset has begun to receive attention from the modeling and simulation community. Romander et al. [5] provided the initial correlation of airloads and performance using the structured CFD code OVERFLOW-2 coupled with CAMRADII. Biedron and Lee-Rausch [6] performed correlation work using unstructured CFD and CAMRADII. Coupled simulations have been particularly effective at predicting airloads for many flight conditions. Comparisons of simulated and measured performance have generally been good but discrepancies remain.

Abrego et al. [7] offered a brief correlation between simulation and measured data for blade motion and deformation. This effort involved only a single, benign flight condition and although some blade motions were well correlated, significant differences were identified in lag motion and elastic bending. The proposed paper will provide a more thorough correlation of blade motion measurements with simulation.

Preliminary Results

Preliminary simulations have been completed using coupled OVERFLOW-2 and CAMRADII. These techniques have been similar to work by Abrego et al. [7] but have improved fidelity through the use of increased grid resolution, a 5th-order accurate numerical scheme, and the Spalart-Almaras Delayed Detached Eddy Simulation (S-A DDES) turbulence model.

From these simulations, two types of data have been extracted for comparison. First are blade root motions which are equivalent to the pitch, flap, and lag hinge displacements. Then, using these motions as a baseline, the two main elastic modes of the rotor (flap and torsion) may be computed. This data is then compared to blade

displacement data as measured using photogrammetry [7].

Two flight conditions have been modeled: high-speed, level flight; and a high-thrust, stalled-rotor condition. The high-speed flight condition was from run 53, point 20. This flight condition was at a μ=0.37, M_{tip}=0.65, and a shaft angle of -8.4°. The rotor was trimmed to C_T/σ=0.08 and representative hub moments. Figure 1 presents the measured and computed flap and lag hinge displacements. Flap angle correlation is generally good for the dominant mean and 1/rev components. Waveform phase is very well matched but there is some tendency to miss the peak values on the retreating side. Lag angle is similarly well matched, however the predicted power is low by approximately 6% which should cause the mean lag angle to be substantially underpredicted. Figure 2 presents the elastic displacement near the tip for this same flight condition. Since elastic deformation accumulates along the blade span, this measure can be seen as a worst-case measure of simulation performance. Both flap and torsional bending exhibit significant mean differences between simulation and measurements. Because the elastic displacements are computed relative to a rigid blade with the same flap and pitch angle, the elastic displacement means are extremely sensitive to error in hinge displacement. Beyond the mean values, the waveforms appear reasonably matched.

The second flight condition was taken from run 42, point 46. This flight condition was at μ=0.24, M_{tip}=0.65, and a shaft angle of 0°. The rotor was trimmed to C_T/σ=0.13 with zero hub moments. At this flight condition, the rotor is deeply stalled. Figure 3 compares flap and lag hinge displacement at this flight condition. The mean and 1/rev flap angle are reasonably correlated with errors similar to the run 53 flight condition. Although the 1/rev lag angle looks good, the mean value is grossly overpredicted. The predicted power is within 1% of the measured value, so the mean should be very close as long as the blade properties are accurately modeled. Figure 4 compares the measured and predicted flap and torsional bending modes. Again, mean error is largely attributable to error in the associated hinge displacement. Oscillatory components are in reasonable agreement.

Proposed Work

Blade airloads, performance, motion, and deformation correlation will be investigated in greater depth. Where possible, blade pitch, flap, and lag will also be correlated with two independent, direct measurements of blade motion provided by mechanical (crab-arm) and laser-based systems. An understanding of the poor prediction of mean lag angle will be sought.

Additional flight conditions will also be investigated. A low-speed, BVI case is currently being simulated, and slowed rotor data with an advance ratios of 0.6 and 1.0 are being reviewed.

References

1. Norman, T. R., Shinoda, P., Peterson, R. L., Datta, A., “Full-Scale Wind Tunnel Test of the UH-60A Airloads Rotor”, American Helicopter Society 67th Annual Forum, May 2011.
2. Kufeld, R. M., Dwight L. Balough, Jeffrey L. Cross, Karen F. Studebaker, Christopher D. Jennison, and William G. Bousman, “Flight Testing the UH–60A Airloads Aircraft,” American Helicopter Society 50th Annual Forum, May 1994.
3. Potsdam, M., Yeo, H., Johnson, W., “Rotor Airloads Prediction Using Loose Aerodynamic/Structural Coupling”, American Helicopter Society 60th Annual Forum, June 2004.
4. Nygaard, T., Saberi, H., Ormiston, R. A., Strawn, R. C., and Potsdam, M., “CFD and CSD Coupling Algorithms and Fluid Structure Interface for Rotorcraft Aeromechanics in Steady and Transient Flight Conditions”, American Helicopter Society 62nd Annual Forum, May 2006.
5. Romander, E., Norman, T. R., and Chang, I-C., “Correlating CFD Simulation With Wind Tunnel Test for the Full-Scale UH-60A Airloads Rotor”, American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 3-5, 2011.
6. Biedron, R. and Lee-Rausch, E., “Computation of UH-60A Airloads Using CFD/CSD Coupling On Unstructured Meshes”, American Helicopter Society 67th Annual Forum Proceedings, 2011.

7. Abrego, A. I., et al., "Blade Displacement Measurement Technique Applied to a Full-Scale Rotor Test", American Helicopter Society 68th Annual Forum Proceedings, 2012.

Figures

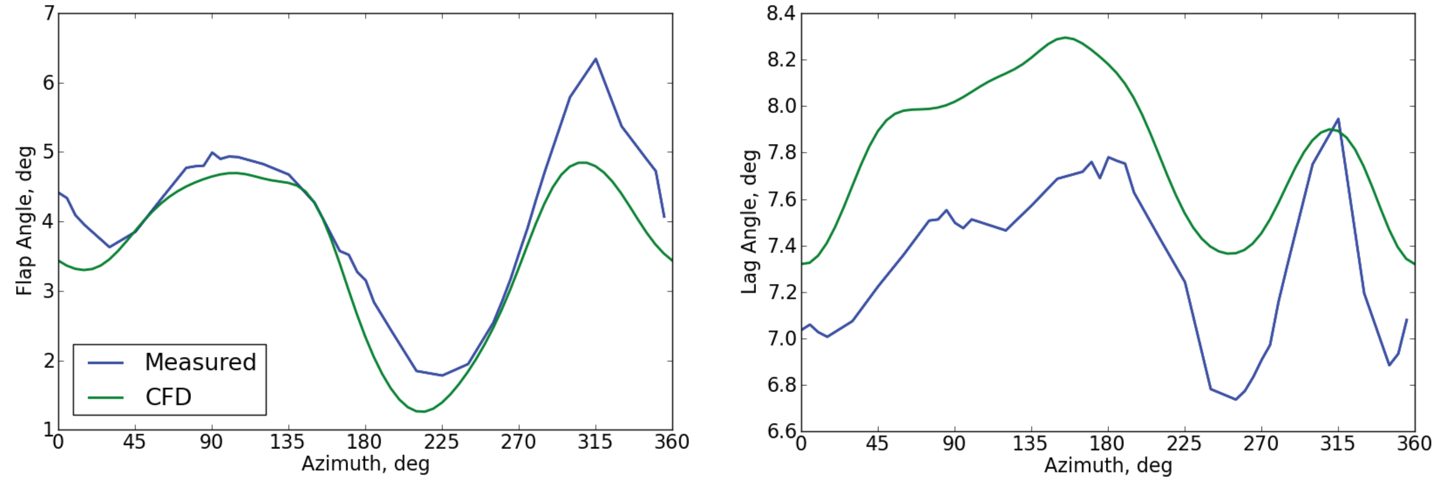

Figure 1: Measured (blue) and predicted (green) flap and lag hinge displacement for run 53, point 20.

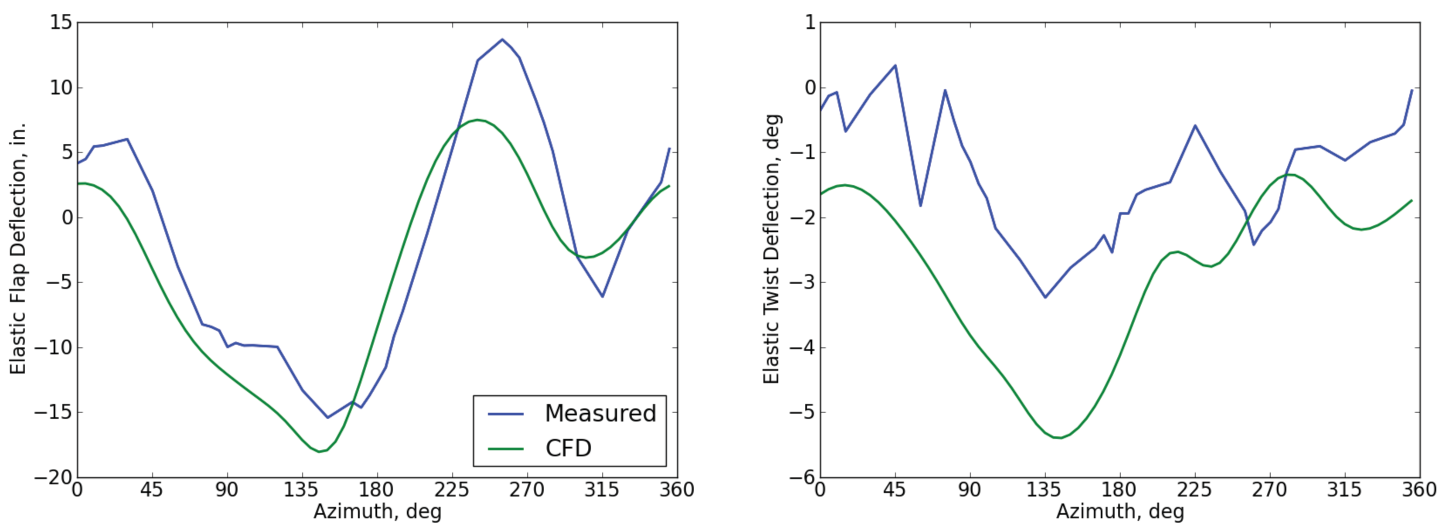

Figure 2: Measured (blue) and predicted (green) flap and torsional bending for run 53, point 20.

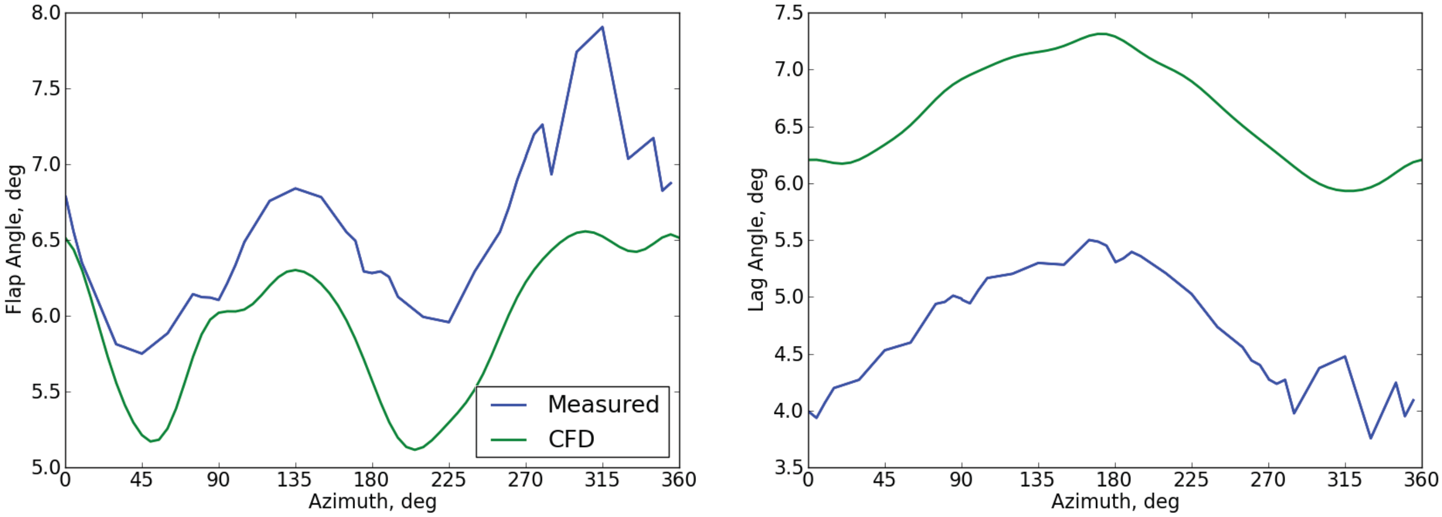

Figure 3: Measured (blue) and predicted (green) flap and lag hinge displacement for run 42, point 46.

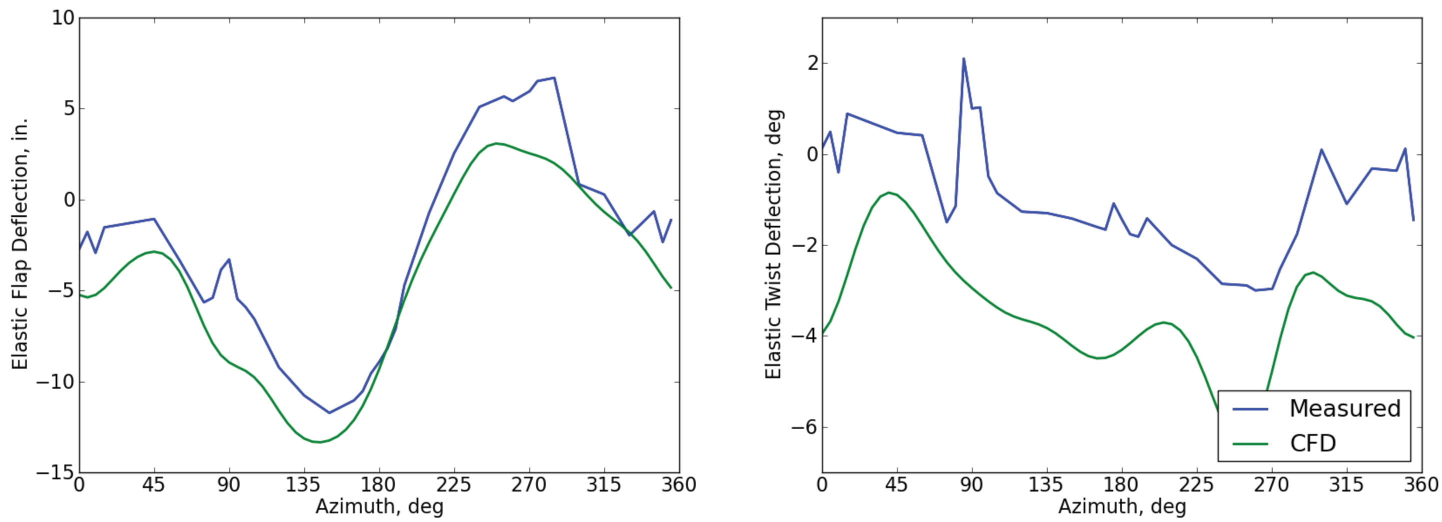

Figure 4: Measured (blue) and predicted (green) flap and torsional bending for run 42, point 46.